AD-A246 150

TECHNICAL REPORT RD-GC-91-6

EFFECT OF GYRO NOISE ON ADKEM GYRO-ONLY MISSILE SYSTEM PERFORMANCE

Vicki C. LeFevre
Guidance and Control Directorate
Research, Development, and Engineering Center

September 1991

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

Approved for public release; distribution is unlimited.

DESTRUCTION NOTICE

FOR CLASSIFIED DOCUMENTS, FOLLOW THE PROCEDURES IN DoD 5200.22-M, INDUSTRIAL SECURITY MANUAL, SECTION II-19 OR DoD 5200.1-R, INFORMATION SECURITY PROGRAM REGULATION, CHAPTER IX. FOR UNCLASSIFIED, LIMITED DOCUMENTS, DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENT.

DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) TR-RD-GC-91-6	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Guidance & Control Directorate RD&E Center 6b. OFFICE SYMBOL (If applicable) AMSMI-RD-GC	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Commander, U.S. Army Missile Command ATTN: AMSMI-RD-GC-N Redstone Arsenal, AL 35898-5254	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)

Effect of Gyro Noise on ADKEM Gyro–Only Missile System Performance

12. PERSONAL AUTHOR(S)

Vicki C. LeFevre

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM Jan 91 TO Mar 91	1991 September	24

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	ADKEM	Gyro–Only	Hypervelocity
			Noise Effects	System Performance	A/D Converson

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report presents results from a series of deterministic and Monte Carlo runs which indicate that the addition of three bits of noise to the sixteen bit A/D converter used with the gyros that will be mounted on the gyro–only demonstration ADKEM flight vehicles will not adversely affect system performance. These results are based on modeling the three bits of noise on the gyros and using Monte Carlo statistical analysis to quantify its effects on system performance.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Vicki C. LeFevre	22b. TELEPHONE (Include Area Code) (205) 876-8098 22c. OFFICE SYMBOL AMSMI-RD-GC-N

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

Results from a series of deterministic and Monte Carlo runs indicate that the addition of three bits of noise to the sixteen bit A/D converter used with the gyros that will be mounted on the gyro–only demonstration ADKEM flight vehicles will not adversely effect system performance. These results are based on modeling the three bits of noise on the gyros and using Monte Carlo statistical analysis to quantify its effects on system performance.

I. INTRODUCTION

Tests in the Guidance and Control integration facility have indicated that three bits of noise are degrading the gyro data when the real–time controller writes its DAC outputs. RD–GC–S personnel, in charge of the breadboard coding, have decided that instead of truncating the last three bits on the sixteen bit A/D, they would allow the noise to remain. It was decided to simulate this condition by adding three bits of noise to the gyro outputs in the ADKEM 6–DOF digital simulation and analyze the effects on performance. This will also allow the outputs from the 6–DOF to be compared to outputs from G&C integration testing. If serious degradation occurs from the use of noisy data, then the alternative would be to truncate the last three bits of gyro data. The ADKEM simulation and performance is documented in [1,2,3].

II. GENERAL SYSTEM CHARACTERISTICS

Quantization of data in the sensor subroutine causes some error in actual versus sensed angular rates in the pitch, yaw and roll axes. The addition of three bits of noise will further degrade the sensed angular rates coming from the gyros. It was decided that the ADKEM 6–DOF simulation would be modified to simulate three bits of noise on the sixteen bit A/D and system analysis would indicate that the noise was or was not a problem area in terms of effect on overall system performance. Deterministic and Monte Carlo runs were made in order to characterize the effect of the noise on the system.

The code that simulates the three bits of noise added to the gyro output is as follows:

```
PQNT  =   (NINT((PSM*4095.)/(1500.*DTR))*8.
        + NINT(14.*RAN(ISEED) -7.)) / (32767. / (1500.DTR))

QQNT  =   (NINT((QSM*4095.)/(1500.*DTR))*8.
        + NINT(14.*RAN(ISEED) -7.)) / (32767. / (1500.*DTR))

RQNT  =   (NINT((RSM*4095.) / (1500.*DTR))*8.
        + NINT(14.*RAN(ISEED) -7.)) / (32767. / (1500.*DTR))
```

where PSM is the sensed roll rate measured by the roll gyro,
QSM is the sensed pitch rate measured by the pitch gyro,
RSM is the sensed yaw rate measured by the yaw gyro.

The gyro accuracy is dependent on the total range that the gyro can measure and the number of bits available to represent that measured number. The sixteen bit A/D is available to measure $\pm$1500 degrees per second which is a total range of 3000 degrees per second. This is the equivalent of using a range of 1500 degrees per second with a fifteen bit A/D available since

$$3000./2^{n} = 1500./2^{(n-1)}$$

where n is the number of bits available.

Accordingly, the 4095 is derived from $2^{12} = 4096$. Since 0 is considered to be an acceptable number, 0 – 4095 represents 4096. This number is the fifteen bit A/D available, but with the last three bits truncated for the addition of noise.

Similarly, the 32767 is derived from $2^{15} = 32768$ and again allowing 0 moves the sliding scale from 0 – 32767. The random number generator picks some number between 0 and 1 with equal probabilities associated with each choice in the interval (uniform distribution). As a result, the random number added to

NINT ((PSM*4095.)/(1500.*DTR))*8 .

which is represented by

NINT(14.*RAN(ISEED) –7.)),

will be some integer from –7 to +7. This range of values represents three bits of noise since $2^3 = 8.0$ and again this represents values from 0 –7.

The gyros are capable of measuring up to ± 1500 degrees per second of angular rate. The first part of the code takes the actual rate, truncates the last three bits, divides by the range that the gyro can measure in radians per second and converts that value to to an integer format. The second part of the code picks a random number between 0 and 1 from a uniform distribution, multiplies the random number by fourteen, subtracts 7 to map the result into a range between ± 7 and converts that value to an integer format. The second part is then added to the first part which is the equivalent of adding three bits of noise to the first thirteen good bits. The resulting integer is divided by the quantization level for a sixteen bit accuracy number.

III. RESULTS

When the Monte Carlo runs were made with and without noise added to the gyro output, the results were similar. For both sets of runs, which consisted of 100 runs per Monte Carlo set, all cases resulted in successful engagement of the target. The target was placed at 750 feet downrange and 750 feet crossrange. For the 100 run set without noise, the CEP was 4.21 feet and 19 out of the 100 cases had miss distances of less than one meter. All 100 cases had an angle–of–attack at the point of closest approach which was less than one degree. The vertical component of miss distance had a mean of 2.14 feet and a standard deviation of 3.92 feet. The y–component of miss distance had a mean of – 0.65 feet and a standard deviation of 3.23 feet.

For the 100 run set with noisy gyros, the CEP was 4.25 feet and 22 out of the 100 cases had miss distances of less than one meter. All 100 cases had an angle–of–attack at the point of closest approach which was less than one degree. The vertical component of miss distance had a mean of 1.86 feet and a standard deviation of 3.89 feet. The y–component of miss distance had a mean of – 0.63 feet and a standard deviation of 3.33 feet. The largest miss distance recorded was 15.513 feet. Eight of the runs had miss distances that were in excess of 10.0 feet.

Deterministic runs were made with the target placed at 750.0 feet downrange, 750.0 feet crossrange, and with an initial yaw angle of 45.0 degrees. Runs were made for the case of noisy gyros and gyros with no noise.

Figures 1–10 were generated with the target at 750.0 feet downrange, 750.0 feet crossrange, and with an initial yaw angle of 45.0 degrees. All the figures are for deterministic runs.

Figures 1–3 depict the true pitch, yaw, and roll angular rates and the gyro derived values for the pitch, yaw and roll angular rates versus time for the case of no noise on the gyros. The roll and yaw rates are so benign that the quantization level is never reached, PQNT and RQNT remain zero for the entire flight.

Figure 4 expands the region of time between 0.0 and 0.3 for the pitch channel so that the effects of quantization for the no noise case can be identified.

Figures 5–7 depict the true pitch, yaw, and roll angular rates and the gyro derived values for the rates versus time when there are three bits of noise on the sixteen bit A/D.

The output of the quantization code for the noisy gyros is depicted in Figures 8–10. Although the addition of noise is evident from the Figures 8–10, the three bits of noise at worst case level add only about 0.32 degrees per second to the rates. Since the flight is of exceptionally short duration, this is equivalent to a worst case of approximately one tenth of a degree of pitch angle.

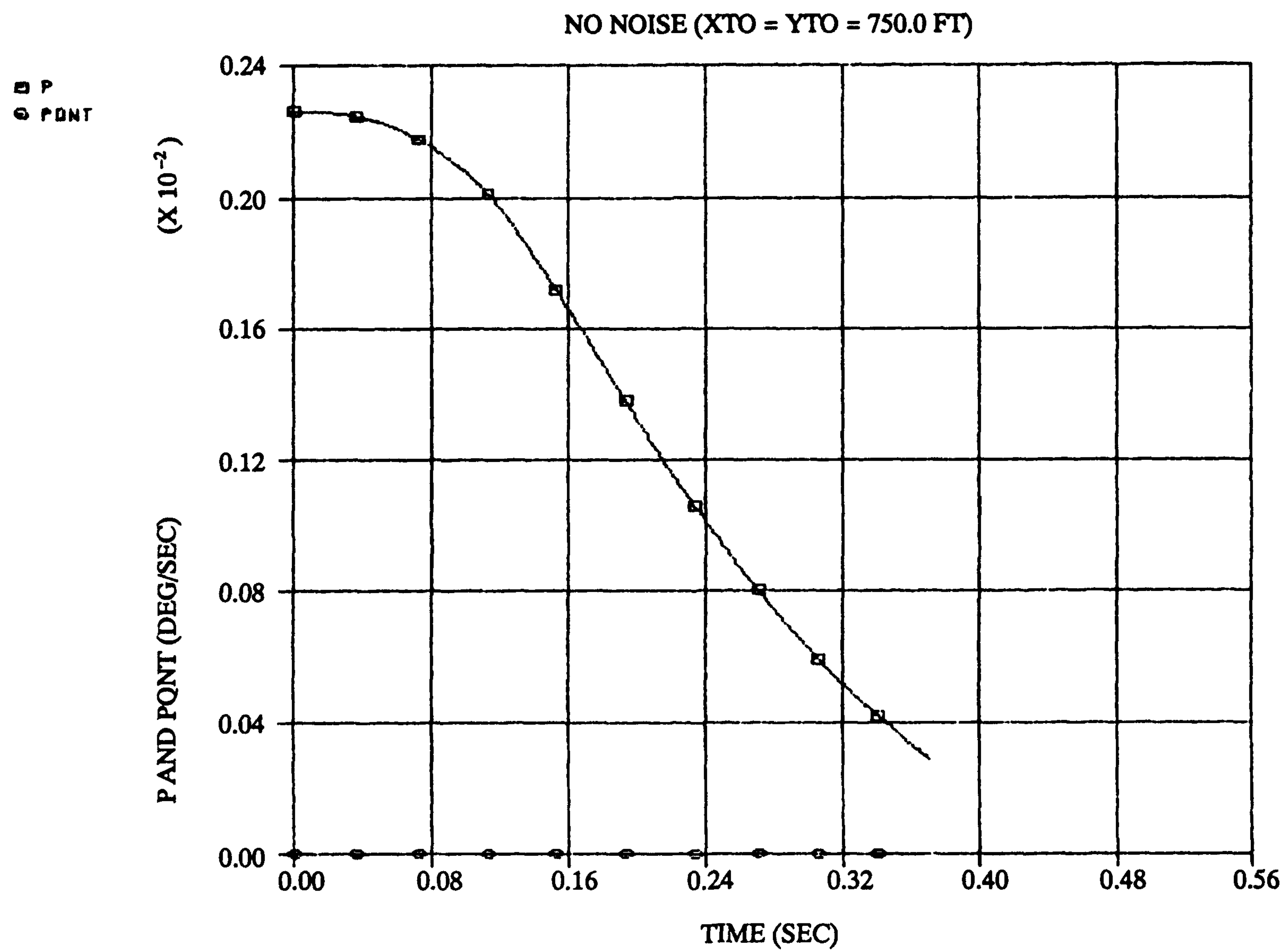

Figure 1. Roll Rate and Quantized Roll Rate Versus Time.

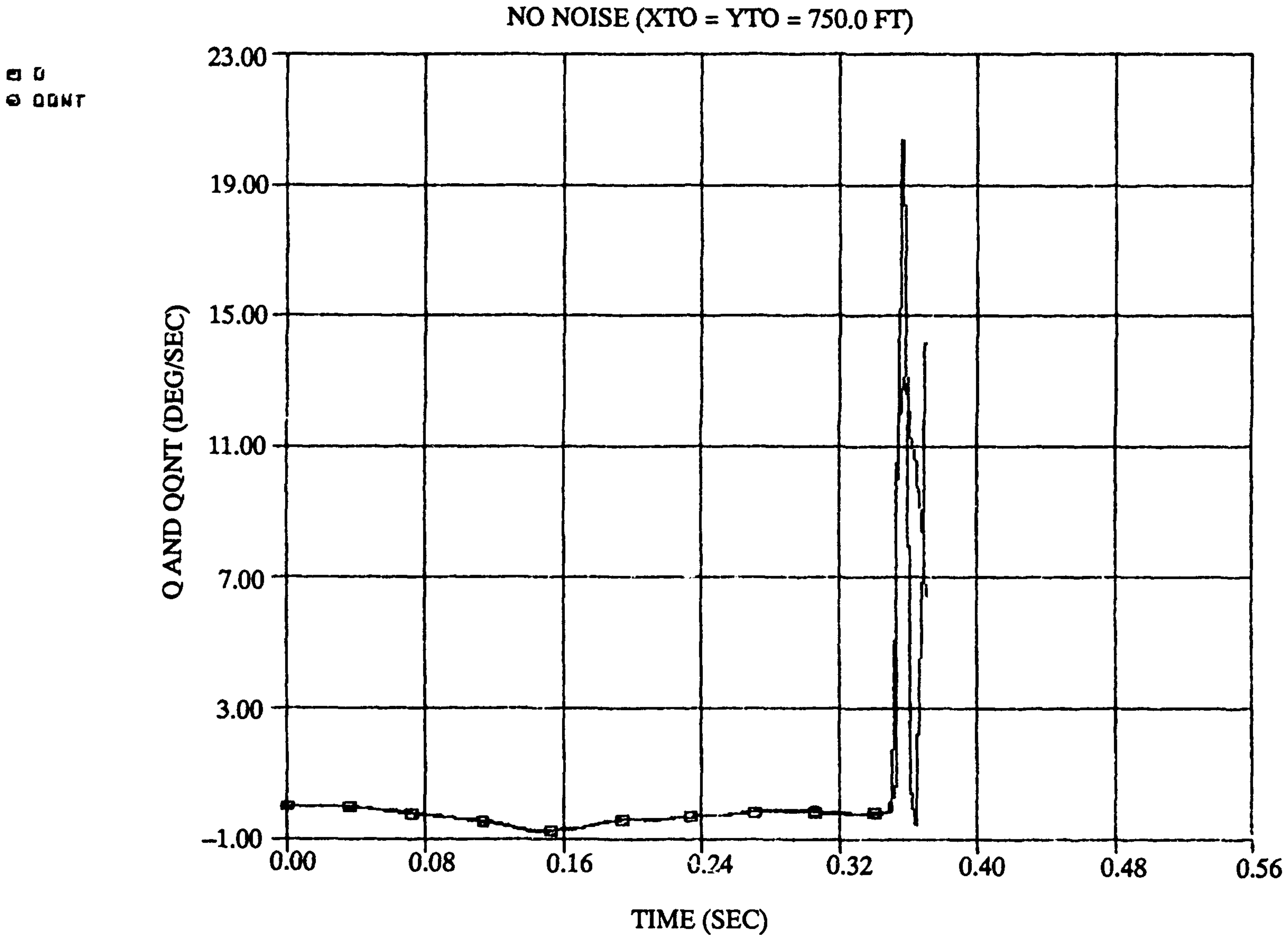

Figure 2. Pitch Rate and Quantized Pitch Rate Versus Time.

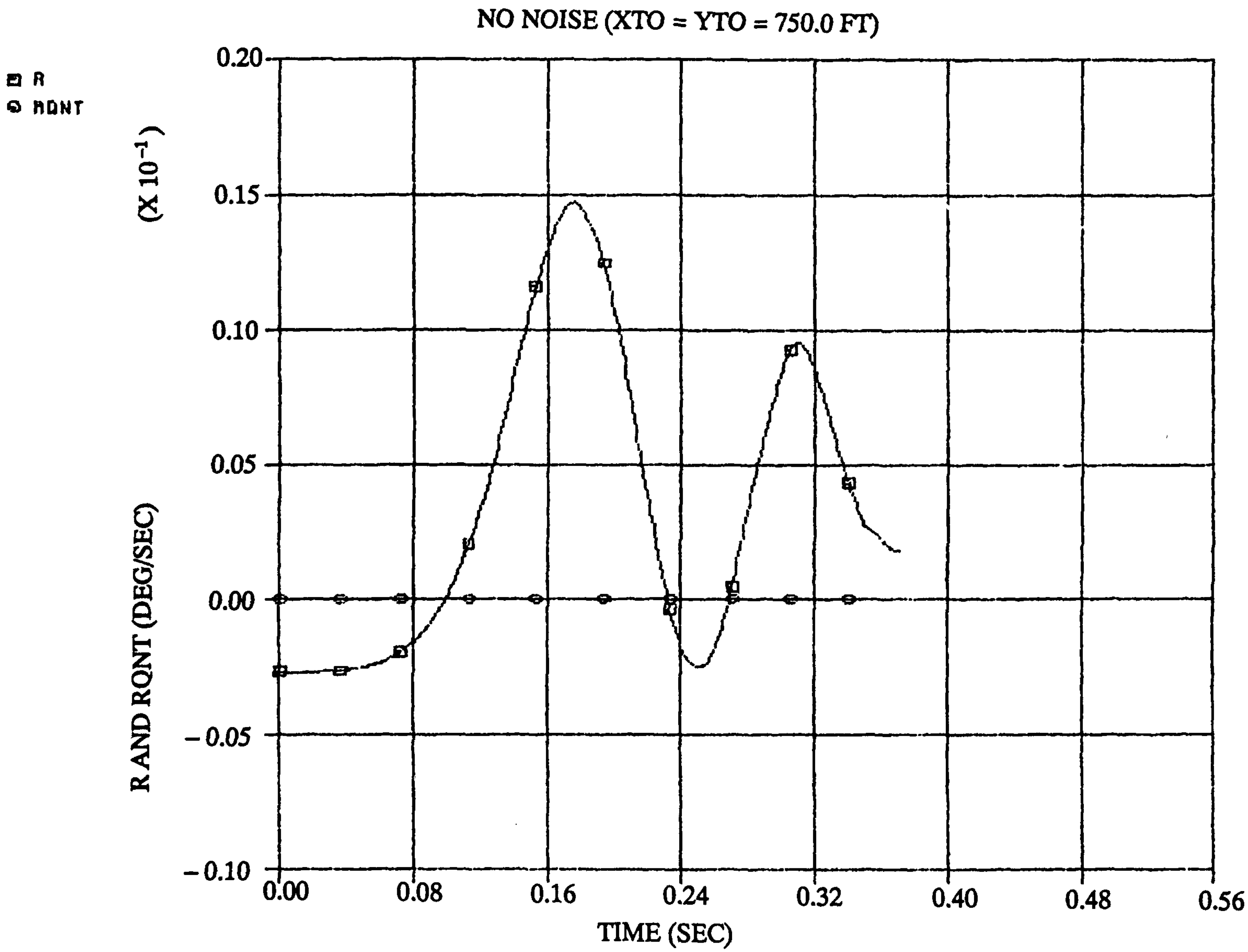

Figure 3. Yaw Rate and Quantized Yaw Rate Versus Time.

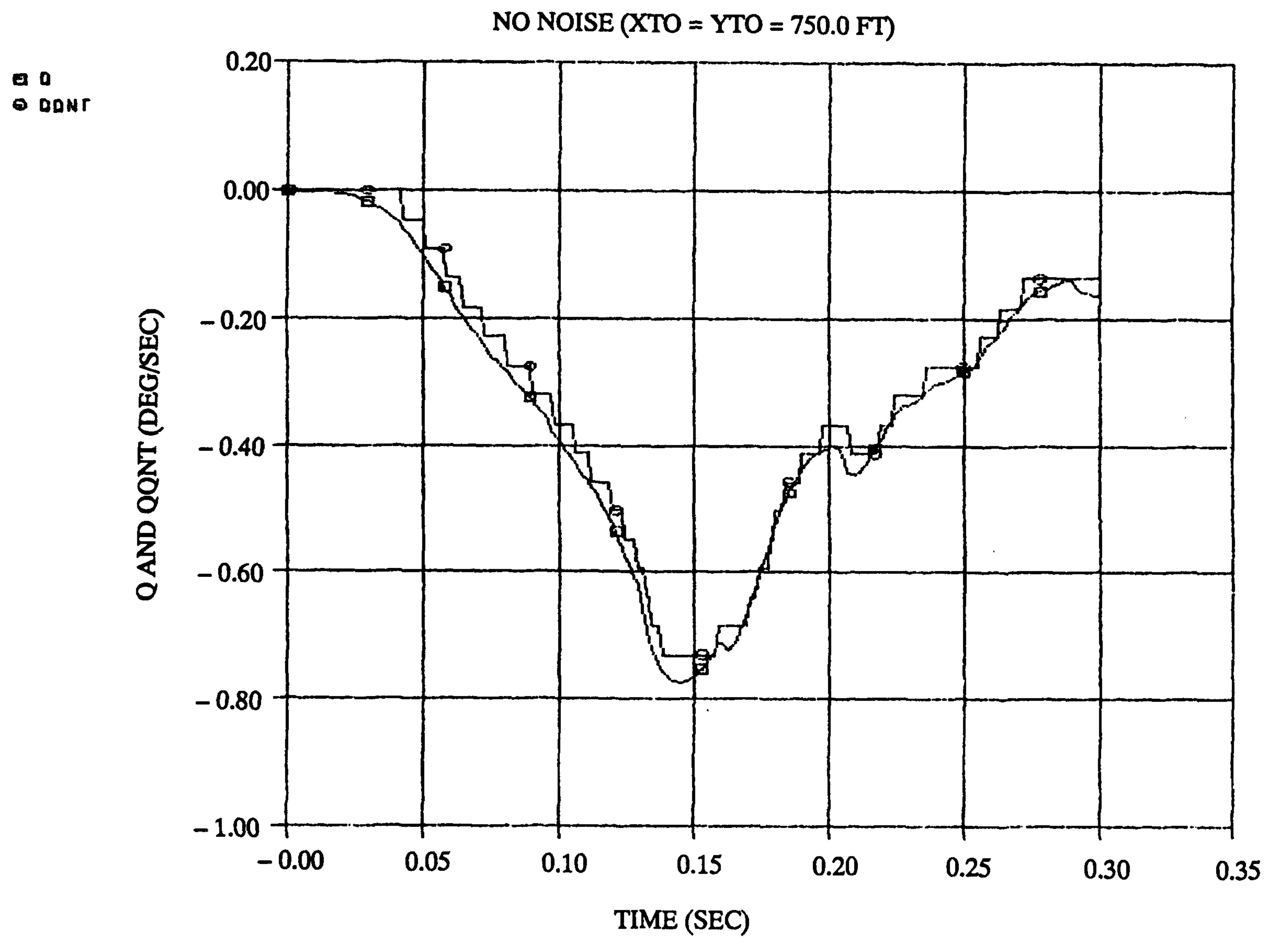

Figure 4. Pitch Rate and Quantized Pitch Rate Versus Time.

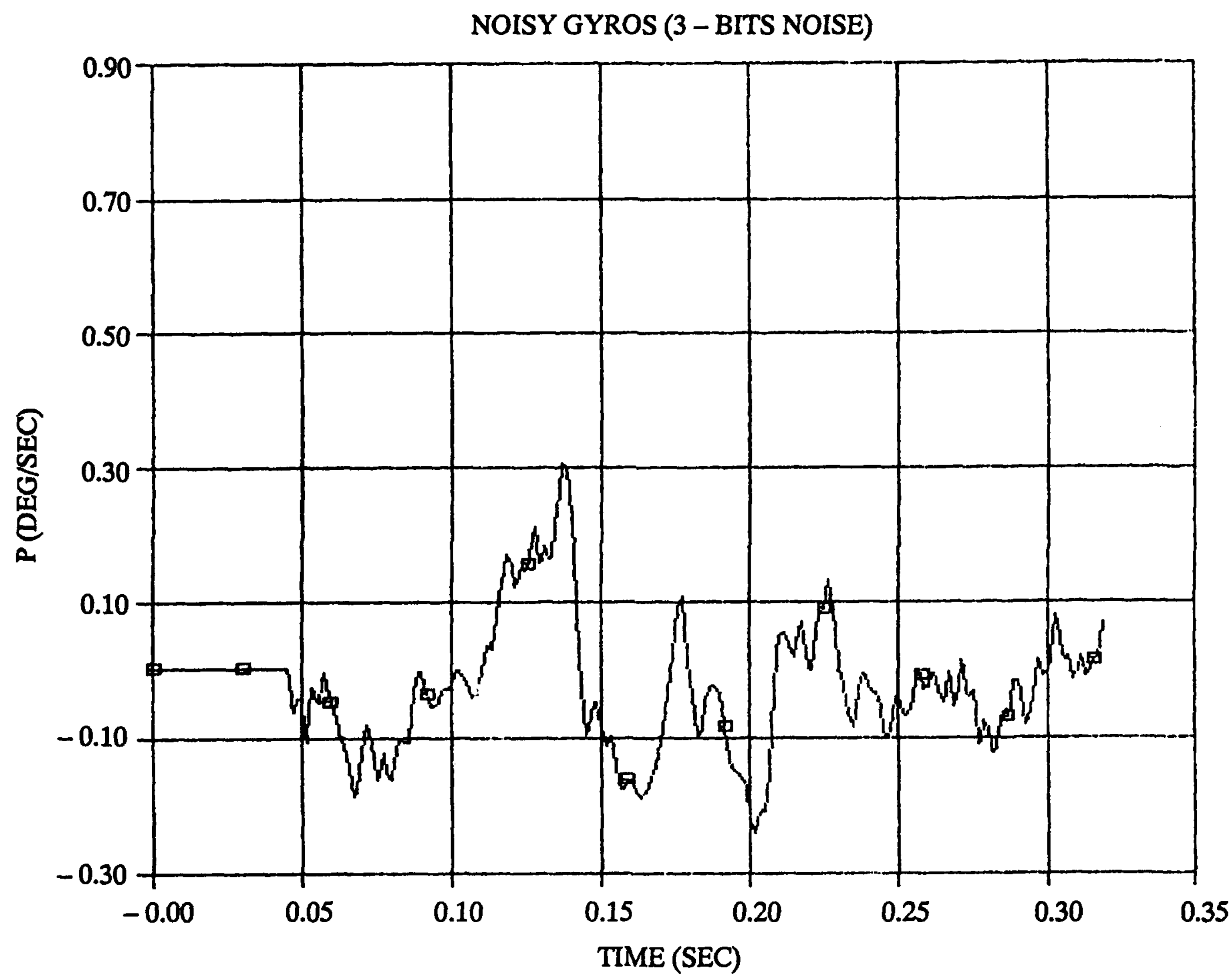

Figure 5. Roll Rate Versus Time.

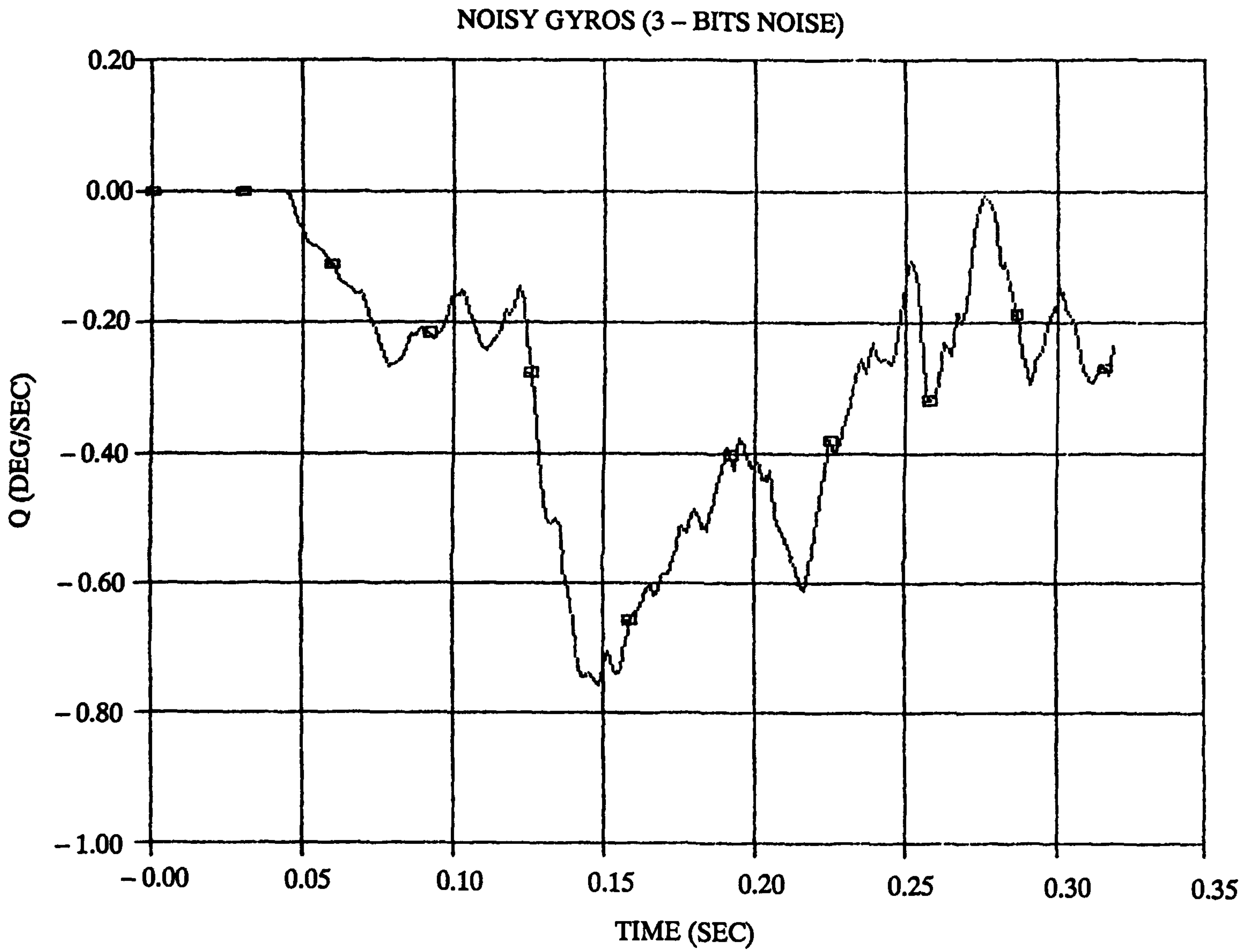

Figure 6. <u>Pitch Rate Versus Time.</u>

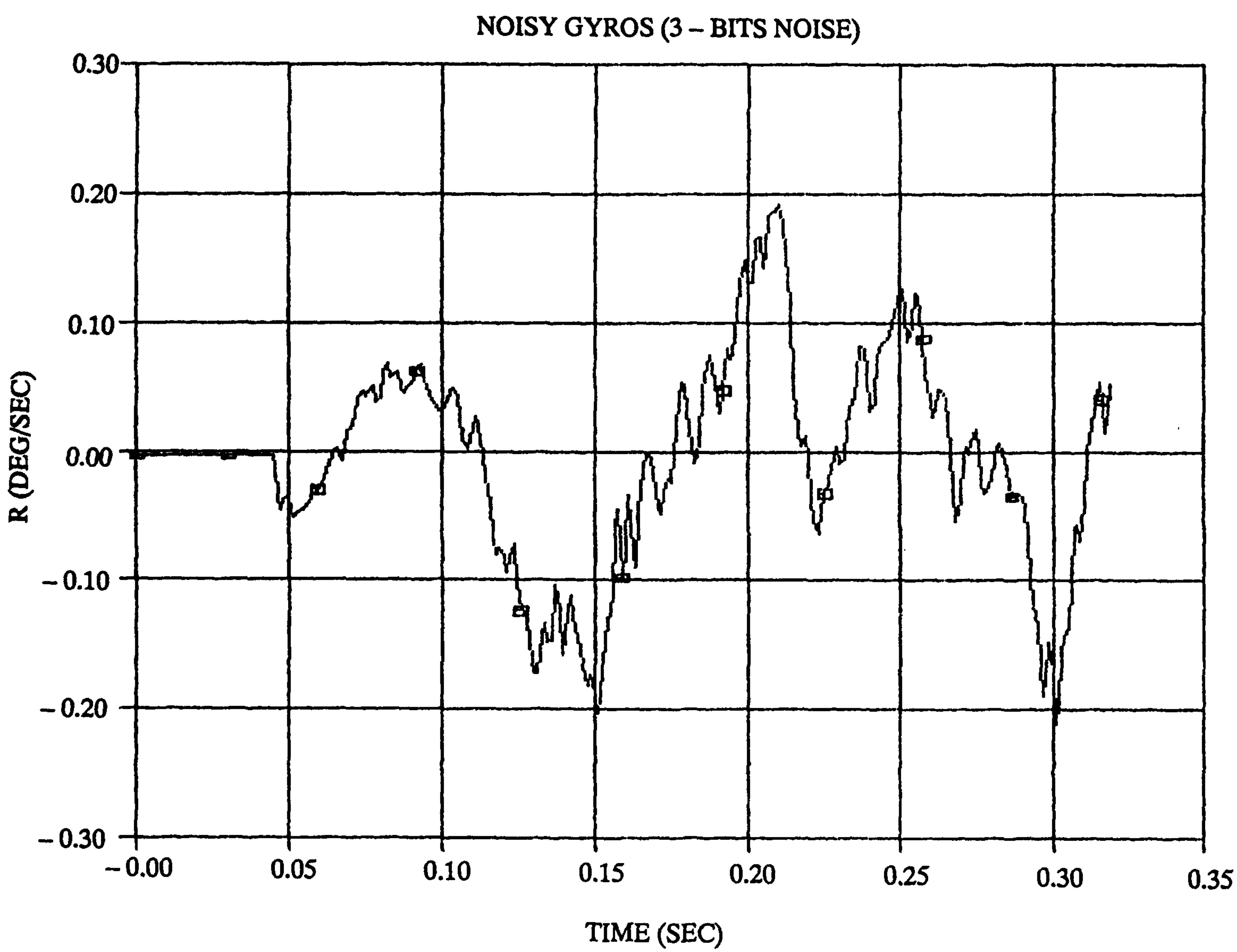

Figure 7. Yaw Rate Versus Time.

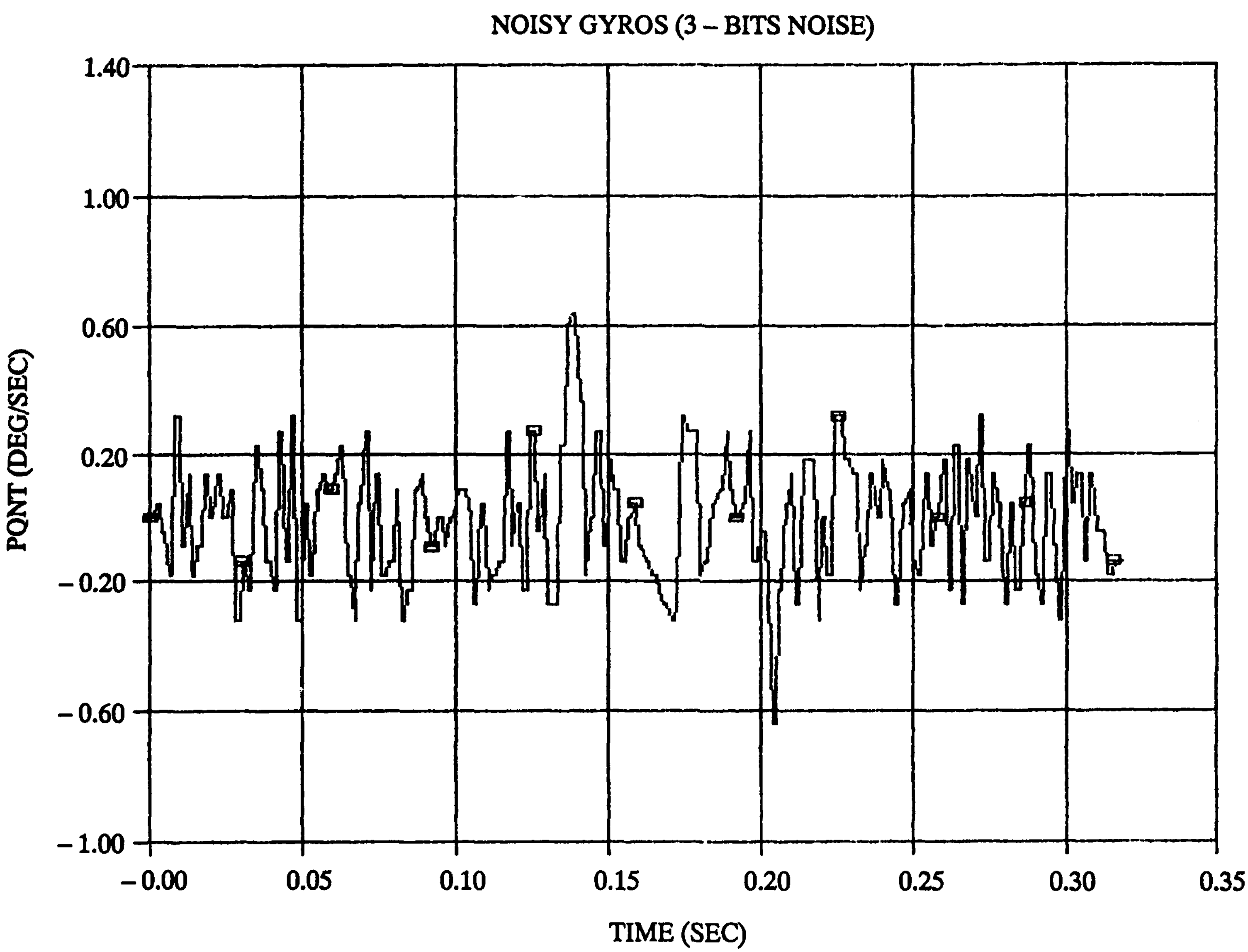

Figure 8. Quantized Roll Rate Versus Time.

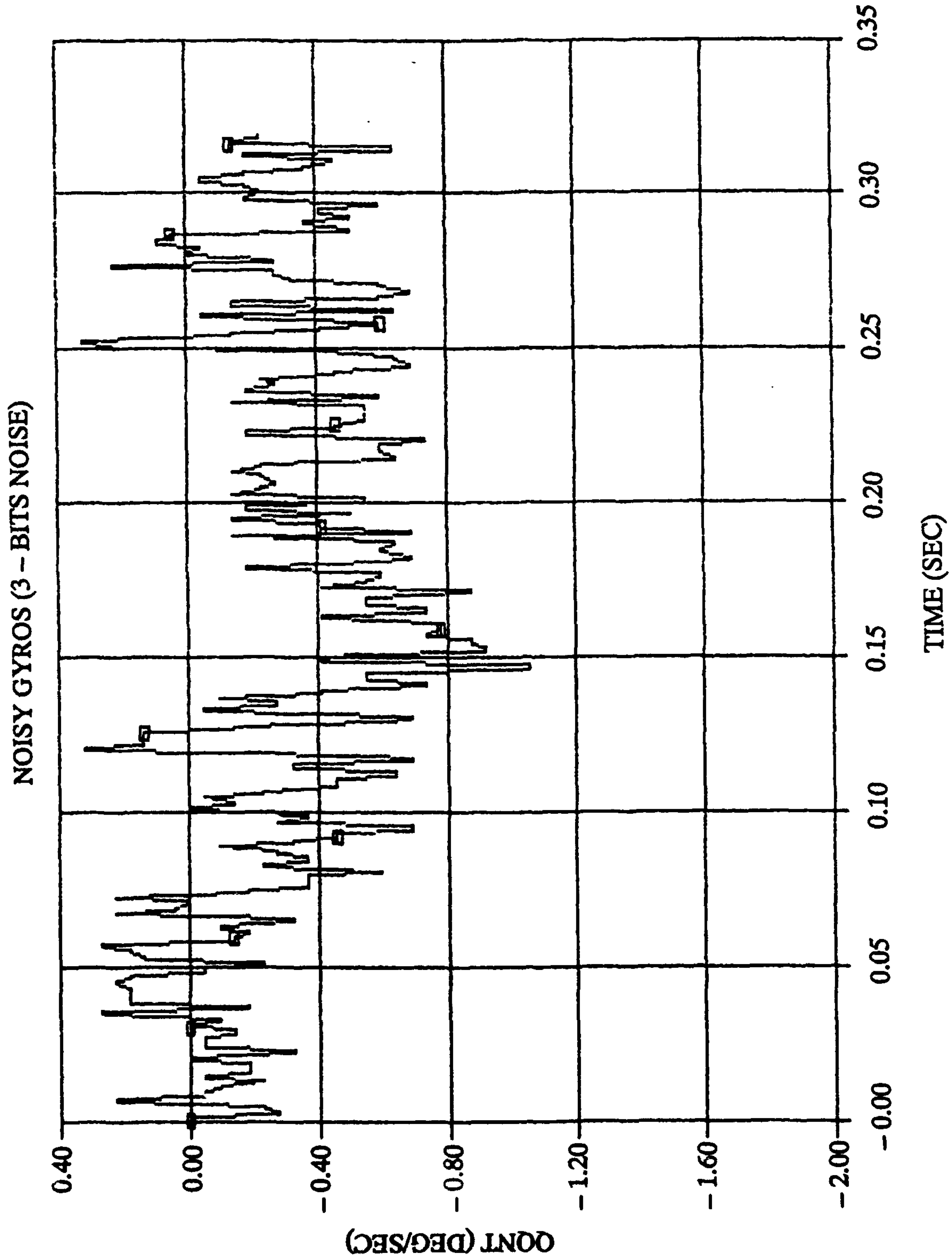

Figure 9. Quantized Pitch Rate Versus Time.

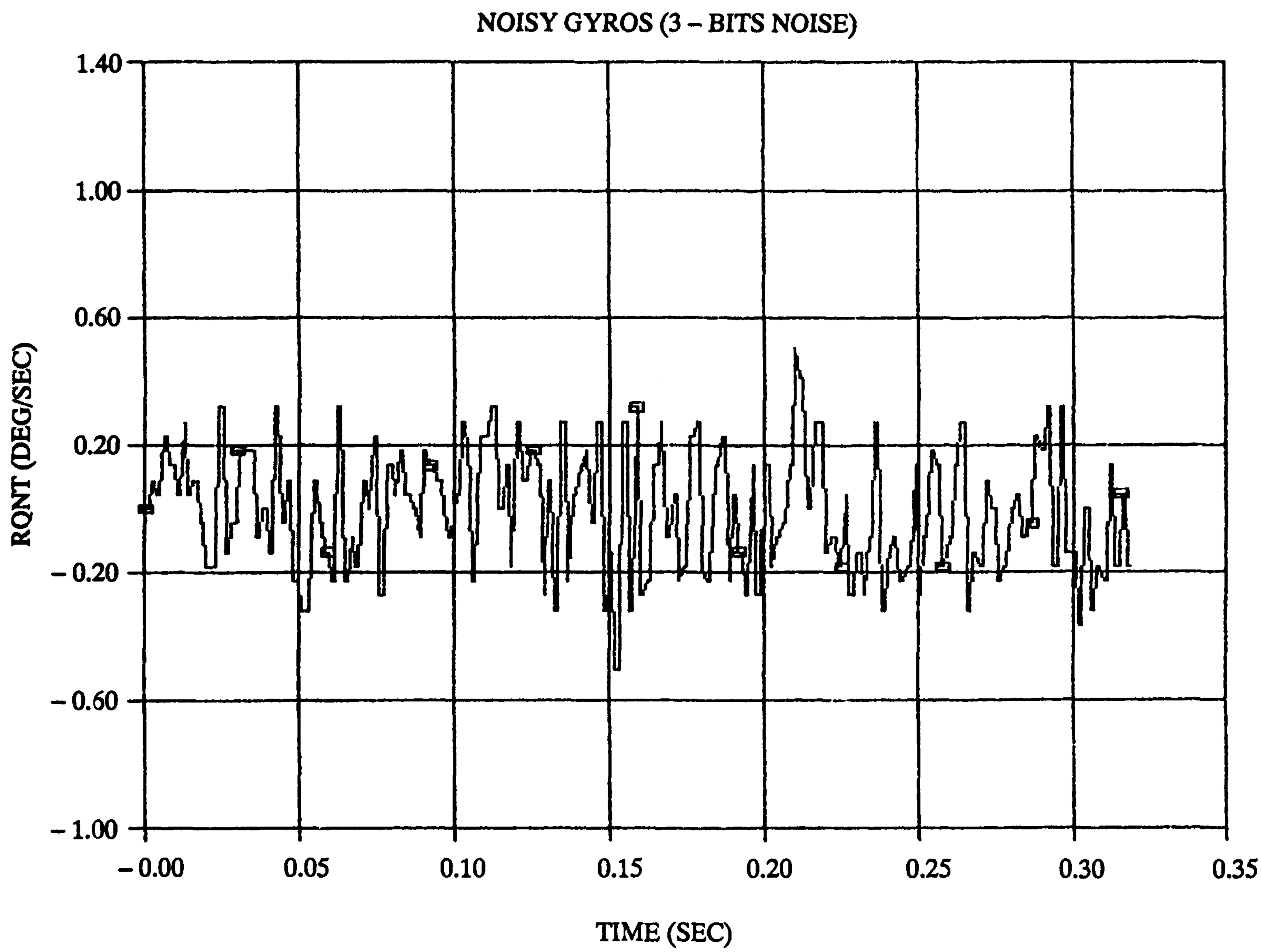

Figure 10. Quantized Yaw Rate Versus Time.

Table 1 presents a twenty run sample of the data generated using noisy gyros. Table 2 presents a twenty run sample of the data generated using gyros with no noise. For each of the twenty individual runs, the random number seed was identical. So the error sources for both the noisy gyros and the gyros with no noise were the same. Comparisons for individual runs from no noise were the same. Comparisons for individual runs from Table 1 versus Table 2 clearly show some difference due to the addition of three bits of noise to the gyros. In all cases, the difference in results can be considered to be negligible. As a result of this study, there is no recommendation to truncate the last three bits of gyro data. There is no significant contribution to system performance if the three bits of noise are allowed to propagate throughout the flight.

TABLE 1. Noisy Gyros.

Run #	Time	Miss Distance	Total Angle–of–Attack
1	0.3720	10.194761	0.252541
2	0.3715	1.571559	0.151627
3	0.3735	5.889752	0.718475
4	0.3750	4.221075	0.203798
5	0.3690	4.691263	0.076970
6	0.3690	1.308397	0.206063
7	0.3750	5.087620	0.177291
8	0.3705	7.177988	0.197431
9	0.3725	4.174479	0.488148
10	0.3745	3.767153	0.672226
11	0.3720	6.307410	0.143421
12	0.3690	12.261572	0.192022
13	0.3665	7.866381	0.200126
14	0.3705	5.845677	0.251877
15	0.3690	4.887487	0.190072
16	0.3755	3.489435	0.066593
17	0.3710	2.522624	0.125063
18	0.3735	2.791847	0.347327
19	0.3720	4.226913	0.044479
20	0.3700	8.723343	0.169355

TABLE 2. No Noise.

Run #	Time	Miss Distance	Total Angle-of-Attack
1	0.3720	10.195145	0.254136
2	0.3715	1.639293	0.150164
3	0.3735	5.925084	0.718771
4	0.3750	4.220079	0.201979
5	0.3690	4.796886	0.079784
6	0.3690	1.304805	0.204696
7	0.3750	5.155031	0.185946
8	0.3705	7.228868	0.196987
9	0.3725	4.151514	0.486061
10	0.3745	3.798571	0.672603
11	0.3720	6.300007	0.146244
12	0.3690	12.304220	0.189572
13	0.3665	7.860584	0.202442
14	0.3705	5.880535	0.243554
15	0.3690	4.925600	0.191184
16	0.3755	3.454409	0.063282
17	0.3710	2.568705	0.125924
18	0.3735	2.796681	0.349178
19	0.3720	4.225072	0.047524
20	0.3700	8.772769	0.170381

Table 3 was generated with noisy gyros and with the same conditions as the data for Table 1. The only difference is that the data in Table 3 was generated with the 1023 Hz filter and the 323 Hz notch filter fully operational. The previous results were for cases without these filters operating. The results are not significantly different. Therefore, in the interest of eliminating long run times, the simplified version of the sensors was used to generate the 100 run set Monte Carlo data.

TABLE 3. Noisy Gyros with Notch and 1023 Hz Filter Incorporated.

Run #	Time	Miss Distance	Total Angle-of-Attack
1	0.3716	10.201940	0.251521
2	0.3711	1.617352	0.161430
3	0.3735	5.947808	0.721107
4	0.3746	4.238001	0.209129
5	0.3688	4.823911	0.077953
6	0.3690	1.298272	0.195450
7	0.3749	5.118810	0.205701
8	0.3704	7.313088	0.205767
9	0.3723	4.156935	0.481069
10	0.3745	3.887272	0.683626

IV. CONCLUSIONS AND RECOMMENDATIONS

The addition of three bits of noise on the sixteen bit ADC has no appreciable effect on system performance. The possibility exists that the ADC will change from a sixteen bit to a fourteen bit conversion. It is also possible that the fourteen bit will only have two bits of noise. If this occurs, the noise issue will need to be re–examined to make sure there are still no adverse effects on system performance.

REFERENCES

1. Gratt, Harvey and Delilah Smith, ADKEM Performance Analysis, Document NRC–TR–90–179, Huntsville, AL, 30 September 1990.

2. Gratt, Harvey and Delilah Smith, Guidance and Control Design for Advanced Kinetic Energy Missile (ADKEM), Document NRC–TR–90–167, Huntsville, AL, 30 July 1990.

3. Thompson, Jon, ADKEM Simulation Development and Analysis, Document NRC–TR–90–189, 31 December 1990.

DISTRIBUTION LIST

	Copies
AMSMI–RD,	1
AMSMI–RD–CS–R	15
AMSMI–RD–CS–T	1
AMSMI–GC–IP, Mr. Fred H. Bush	1
U.S. Army Materiel System Analysis Activity ATTN: AMXSY–MP (Herbert Cohen) Aberdeen Proving Ground, MD 21005	1
IIT Research Institute ATTN: GACIAC 10 W. 35th Street Chicago, IL 60616	1
AMSMI–RD–GC–N, Dr. Paul Jacobs	1
–RD–GC–N, Mr. McLean	1
–RD–GC–N, Ms. LeFevre	3
–RD–GC–N, Dr. McCowan	3
–RD–GC–R, Reference Copy	1